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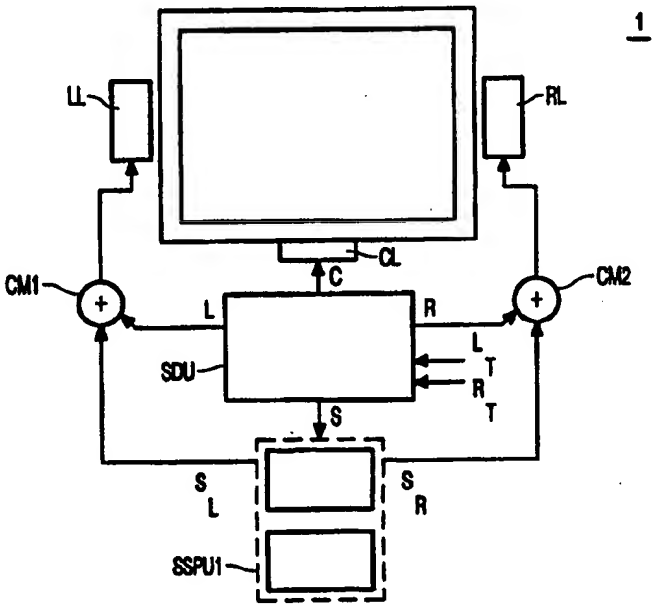
(57) Abstract

To improve listener perceived characteristics multi-channel sound reproduction systems are known which include a surround sound channel. It is preferred to reproduce the surround sound signal (S) without having rear loudspeakers, so using the front stereophonic loudspeakers (LL, RL). To improve the surround sound the frequency range of the surround sound signal (S) is divided (by SSPU1) in at least two adjacent frequency bands. After division the two parts (SR, SL) of the surround signal (S) are expanded to further improve the reproduced surround signal. At last the surround signals (SR, SL) are combined (by CM1, CM2) with the respective stereophonic signals (L, R).



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SURROUND SOUND REPRODUCTION SYSTEM, SOUND/VISUAL REPRODUCTION SYSTEM, SURROUND SIGNAL PROCESSING UNIT AND METHOD FOR PROCESSING AN INPUT SURROUND SIGNAL

The invention relates to a sound reproduction system as described in the preamble of claim 1.

The invention further relates to a surround signal processing unit.

The invention further relates to a sound/visual reproduction system comprising a sound reproduction system .

The invention further relates to a method for processing an input surround sound signal.

To improve listener perceived characteristics, multi-channel sound reproduction systems are known which include a surround-sound channel (often referred to in the past as an "ambience" or "special-effects" channel) in addition to left and right (and optimally, centre) sound channels. These systems are now relatively common in motion picture theatres and are becoming more and more common in the homes of the customers. A driving force behind the proliferation of such systems in consumers' homes is the widespread availability of surround-sound home video software, mainly surround-sound motion pictures (movies) made for theatrical release and subsequently transferred to home video media (e.g. videocassettes, videodisks, and broadcast or cable television).

Although home video media have two-channel stereophonic soundtracks, those two channels carry, by means of amplitude and phase matrix encoding four channels of sound information -left, centre, right and surround sound-, usually identical to the two-channel stereophonic motion-pictures soundtracks from which the home video soundtracks are derived. As is also done in the motion picture theatre, the left, centre, right, and surround channels are decoded and recovered by consumers with a matrix decoder, usually referred to as a "surround-sound" decoder. In the home environment, the decoder is usually incorporated in, or is an accessory to a videocassette player, videodisk player, or television set/ video monitor.

In the case where stereophonic sound is reproduced in such a way as to provide a sound field expanding behind a listener or to localise a sound image behind a listener, two (front) loudspeakers are arranged in front of a listener for stereophonic sound

reproduction and at least one or two rear loudspeakers are additionally arranged behind the listener for surround reproduction.

In the ordinary homes, however, since it is difficult to arrange the two rear loudspeakers and the centre loudspeaker from the standpoint of space and cost, in practice only L- and R-channel loudspeakers are installed on the front left and right sides of a listener. In this loudspeaker arrangement, it has become impossible to obtain sufficient surround sound effect. In the case of the sound reproduction system using a monophonic surround signal in particular, although this system has such a feature that a sound field can be obtained on the rear side of a listener or the sound image can be shifted, it has been impossible to obtain such effects as described above without arranging the rear loudspeakers.

To solve the above problem it is known from the European patent application EP-A-0637191 to use a surround signal processing unit (apparatus) whereby a stereophonic sound effect similar to the case where the rear loudspeakers are arranged can be obtained on the basis of the sound reproduction through only the front left and right loudspeakers.

The inputted rear surround signal is processed by filter means and the processed signal is added to one of the stereophonic signals and then outputted to one of the pair of the loudspeakers. Further an inversion signal of the filter processed signal is added to the other of the stereophonic signals and then outputted to the other of the loudspeakers.

A disadvantage of this known sound reproduction system is that the perceived sound depends strongly on the position (of the head of the listener and) of the listener. Further are the filter characteristics complex and dependent on the listener for example of the rear canal, head/torso, and/or pinna, resulting in possible failures of the requested results. Further this known sound reproduction system is complex.

It is an object of the present invention to provide a sound reproduction system that has not the drawbacks of the sound reproduction system as described above and further to provide a robust sound reproduction system whereby the operation of the filter topology is very robust against coefficient quantisation. Further the listeners position will be less relevant for the performance of the sound reproduction system.

To this end a first aspect of the invention provides a sound reproduction system as described in claim 1.

By splitting the frequency range of the rear surround sound in disjunct frequency bands and supplying a first selection to the left loudspeaker and a second selection to the right loudspeaker the spectrum has been widened resulting in a perceived surround sound.

It is to be noticed that when the input signal being for example a MPEG signal having a stereophonic surround sound signal the surround signal processing unit only has to localise these stereophonic surround signal at virtual sound sources located away from the left channel and right channel loudspeakers and no decoding into a first (for example left) and second (for example right) surround signal is necessary.

A second aspect of the invention provides a sound/visual reproduction system as described in claim 3.

The use of the sound reproduction system in a sound/visual reproduction system such as a television receiver, computer monitor etc. enhances the reproduced sound considerable, resulting in a greatly improved customer satisfaction.

A third aspect of the invention provides an surround signal processing unit as described in claim 7.

Such a surround signal processing unit can be used not only by a sound reproduction system and a sound/visual reproduction system such as a television set but also for example in computer sound cards and/or computer (sound) games.

A fourth aspect of the invention provides a method for processing an input surround sound signal as described in claim 9.

By splitting the frequency range of the surround sound signal into at least two frequency bands and expanding the signals to be supplied to respectively the left and right loudspeaker an improved surround sound is obtained.

A sound reproduction system according to the invention provides an efficient implementation of the so called incredible surround sound whereby the filter topology is such that the filter coefficients are more robust against quantisation and require less storage. This is achieved by splitting the frequency range in disjunct frequency bands.

A preferred embodiment of a sound reproduction system according to the

invention has the features of claim 5.

In this way a very simplified sound reproduction system is obtained having the preferred performances.

An embodiment of a sound reproduction system according to the invention has the features of claim 6.

In case no centre loudspeaker is present the centre signal is splitted in a left and a right part, each part can be supplied multiplied by relevant factors when necessary via the respective combining means to the respective left and right loudspeaker.

These and other aspects of the invention will be apparent from and elucidated by the following figures. Herein shows :

Figure 1 a block schematic example of a sound/visual reproduction system,

Figure 2 a block schematic example of a surround signal processing unit,

Figure 3 a first example of a surround signal processing unit,

Figure 4 a frequency response of the decorrolation filters of figure 3,

Figure 5 a second example of a surround signal processing unit,

Figure 6 a frequency response of the filter transfer functions HL and 2HL-1 of figure 5,

Figure 7 a third example of a surround signal processing unit,

Figure 8 a frequency response of the surround signal processing unit of figure 7, and

Figure 9 a frequency response of the filter transfer functions Ha and Hb.

Figure 1 shows a sound/visual reproduction system 1, such as a television set, comprising a left channel loudspeaker LL and a right channel loudspeaker RL and a centre loudspeaker CL. The sound/visual reproduction system further comprises a surround decoder unit SDU for decoding an input signal comprising two components LT and RT into a rear surround signal S and two channel front stereophonic signals L and R and a centre signal C. Further the sound/visual reproduction system comprises a surround signal processing unit SSPU1 for converting the rear surround signal S, in the absence of a rear loudspeaker, into a first and a second surround signal SL and SR and for localising these surround signals at virtual sound sources located away from the left channel and right

channel loudspeakers LL and RL. The first stereophonic signal L is combined with the first surround signal SL in first combining means CM1 and the second stereophonic signal R is combined with the second surround signal SR in second combining means CM2. The output of the first combining means is coupled to the left loudspeaker and the output of the second combining means is coupled to the right loudspeaker.

The surround signal processing unit SSPU1 comprises filter means, which filter means comprises means for dividing a predetermined frequency range of the rear surround signal into at least two adjacent frequency bands, supplying a first selection of frequency band(s) as the first surround signal to the first combining means CM1 and a second selection of frequency band(s) to the second combining means CM2. The first and second selections being substantially disjunct and the sum of the first and second selections covers the predetermined frequency range.

In figure 2 a surround signal processing unit in block schematic form according to the invention is shown. Examples of the surround signal processing unit will be described below with reference to the figures 3, 5 and 7.

Instead of using the centre loudspeaker CL it is also possible in case no centre loudspeaker is present to split the centre signal in two parts, which parts can be supplied via (amended) combining means to respectively the left and right loudspeaker LL and RL.

Figure 2 shows block schematic an surround signal processing unit SSPU2 according to the invention wherein a received surround signal is transferred into two decorrelated signals SFL2 and SFR2 by a decorrelator DEC2. To further improve the surround sound the signals SFL2 and SFR2 are supplied to an expander EXP2 to widen the signals. The surround signal processing unit supplies at outputs a left surround signal SL and a right surround signal SR. These output signals can be supplied to the first and second combining means (see figure 1), to be finally supplied to the left and right loudspeakers.

When the input signal is a MPEG-signal a stereophonic surround signal is available. As a consequence is in that case no decorrelation is necessary.

The expanding (widening) of the surround signals SFL2 and SFR2 can be done in a lot of ways. In the following example (figure 3) a shuffler, filtering with filter transfer functions Ha, Hb and a de-shuffler is used which is a very efficient way to perform the expanding of the surround signal. In figures 5 and 7 the expander EXP5 respectively EXP7 has been further optimized by minimizing the elements which are necessary.

Figure 3 shows an example of a surround signal processing unit SSPU3

receiving the surround signal S which signal is supplied to a first decorrelation filter FL31 having a transfer function HL as shown in figure 4a and a second decorrelation filter FR31 having a transfer function HR shown in figure 4b. The decorrelation filters FL31 and FR31 operate as dividing means to divide the frequency range of the surround signal into disjunct parts. The output signals of the filters FL3 and FR3 are supplied to a so called shuffler SH3 of an expander EXP3. This shuffler calculates a sum-signal (SFL3 + SFR3) and a difference-signal (SFL3 - SFR3). These sum-signal and difference-signal are supplied via respectively a filter FL32 with a transfer function Hb (see figure 9) and a filter FR32 with a transfer function Ha (see figure 9) to a so-called de-shuffler DSH3. At the outputs of the de-shuffler are the first and second surround sound signals SL3 and SR3 obtained, to be supplied to the combing means (see figure 1).

The use of a shuffler together with the filters having transfer functions Ha, Hb respectively and a de-shuffler is a preferred embodiment of the expander to widen (expand) the surround sound signals.

Figure 4 shows the most elementary solution to divide the frequency range in two disjunct bands by using a low-pass filter for the first filter FL31 (figure 4a) and a high-pass filter for the second filter FR31 (figure 4b). In this way the lower half (below the frequency Fg) of the frequency range of the rear surround signal S will be supplied to the left loudspeaker LL and the higher half of the frequency range (above the frequency Fg) to the right loudspeaker RL.

Figure 5 shows a second example of a surround signal processing unit SSPU5 receiving the surround signal S from the surround decoder (see figure 1). A simplification has been made by deriving the filter FR31 from the filter FL31 (see figure 3) by using the relation in transfer function HR = 1 - HL. It is to be noticed that it is also possible to use HL = 1 - HR. Using this simplification the scheme of the surround signal processing unit can be simplified as shown in figure 5. In this example the surround signal S is supplied to a filter F5 having a transfer function of 2HL the output signal of this filter is supplied to a positive input of a subtract-unit SUB, which receives at the negative input the signal S resulting in a total transfer function (2HL - 1). The subtract-unit supplies at the output a difference signal which is supplied via a filter FR5 with a transfer function Hb (see figure 9) to a de-shuffler DSH5. At the other input the de-shuffler receives the signal S via a filter FL5 with a transfer function Ha (see figure 9).

Figure 6 shows the transfer function of amplitude versus frequency for HL (dashed line) and (2HL - 1) (solid line). It is clear to see that certain frequency bands

will be passed on to the left loudspeaker and other frequency bands to the right loudspeaker.

Figure 7 shows a preferred example of a surround signal processing unit SSPU7 receiving the signal S from the surround decoder (see figure 1). The filter F5 and the subtract-unit SUB from figure 5 are replaced by an all-pass filter F7 having a transfer function HΦ. In figure 8 the total transfer function of amplitude versus frequency is shown for the example of figure 7. A de-shuffler DSH7 receives at one input the signal S via the filter F7 and the filter FR7. At the other input the de-shuffler receives via a filter FL7 the signal S. At the outputs supplies the de-shuffler the signals SL7 and SR7 which can be supplied to the combining means (see figure 1).

Figure 8 shows the total transfer function from the surround sound signal S to the signals SL (solid line) and SR (dashed line). Peaks in one curve coincide with dips in the other curve.

Figure 9 shows the transfer functions Ha (solid line) and Hb (dashed line) as used in the filters FL32, FR32, FL5, FR5, and FL7, FR7.

The man in the art will realise that a lot of amendments are possible without departing from the invention. So is it possible to as mentioned above to amend the combining means to combine also a splitted centre signal CL and CR in case no centre loudspeaker is present.

The surround signal processing unit according to the invention can be used not only in a sound reproduction system, and/or a sound/visual reproduction system such as a television set but for example also in a computer sound card and/or in computer (sound) games, multi media sets, portable audio equipment etc.
It will be further evident that the filters may be implemented analogue or digital. The order of the filters may be chosen at will, although second order filter have proven to perform satisfactory.

Further as mentioned above when the input signal of the sound/visual reproduction system is a MPEG signal no decorrelation is necessary.

Instead of using the shuffler, filtering and de-shuffler combination whether or not optimized, as an expander to provide a widening of the surround signals the man skilled in the art is well aware of other ways.

By splitting the surround signal into two disjunct selections and by widening (expanding) these selections the reproduced surround sound is enhanced

considerably.

Claims:

1. Sound reproduction system comprising a left channel and a right channel loudspeaker, a surround decoder unit for decoding at least one input signal into at least one rear surround signal and two channel stereophonic signals, a surround signal processing unit for converting the rear surround signal(s) into a first and a second surround signal and for localising these surround signals at virtual sound sources located away from the left channel and the right channel loudspeaker, and first combining means coupled to one of the loudspeakers for combining the first surround signal with one of the stereophonic signals and second combining means coupled to the other loudspeaker for combining the second surround signal with the other stereophonic signal, and the surround signal processing unit further comprises filter means, characterised in that the filter means of the surround signal processing unit comprises dividing means for dividing at least one predetermined frequency range of the rear surround signal(s) into at least two adjacent frequency bands, supplying a first selection of frequency bands as the first surround signal to the first combining means and a second selection of frequency bands as the second surround signal to the second combining means, the first and second selections being substantially disjunct, a sum of the first and second selections covering the predetermined frequency range.

2. Sound reproduction system as claimed in claim 1, characterised in that the dividing means are arranged for alternately supplying consecutive frequency bands as the first and second surround signal.

3. Sound reproduction system as claimed in claim 1, characterised in that the filter means comprises a first and a second decorrelation filter being part of decorrelation means, coupled with output to inputs of a shuffler, outputs of the shuffler are coupled via a third and a fourth filter with a de-shuffler for expanding the surround signals.

4. Sound reproduction system as claimed in claim 1, characterised in that the surround signal processing unit comprises an input coupled to an input of a filter of the filter means which filter has an output coupled to an input of a subtract unit, the other input of the subtract unit is coupled with the input of the filter, the subtract unit is coupled via a second filter to a de-shuffler, the other input of the de-shuffler is coupled via a third filter to the input of the surround signal processing unit.

5. Sound reproduction system as claimed in claim 1, characterised in that the surround signal processing unit comprises an all pass filter, the output of this all pass filter is coupled via a second filter to an input of a de-shuffler, the other input of the de-shuffler is coupled via a second filter to the input of the surround signal processing unit.

6. Sound reproduction system as claimed in claim 1, characterised in that the surround decoder also provides a centre signal having a first and a second part, whereby the first part is supplied via a first scaler to the first combining means and the second part is supplied via a second scaler to the second combining means.

7. Sound/visual reproduction system comprising a sound reproduction system as claimed in claim 1.

8. Surround signal processing unit for use in a sound reproduction system as claimed in claim 1.

9. Method for processing an input surround signal into a left and a right channel output signal characterised in that the method comprises the steps of

- dividing a predetermined frequency range of the input surround sound signal into at least two adjacent frequency bands,
- supplying a first selection of frequency band(s) to form after expanding the left channel output signal,
- supplying a second selection of frequency band(s) to form after expanding the right channel output signal,

the first and second selections being substantially disjunct, a sum of the first and second selections covering the predetermined frequency range.

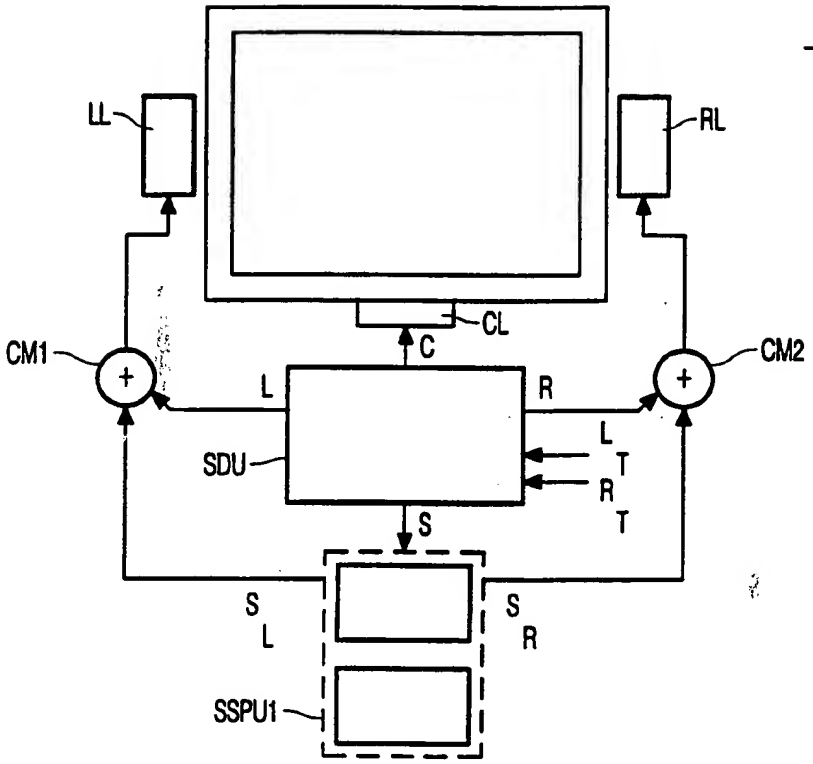
1
LL
RL
CL
C
CM1
CM2
L
R
SDU
L T
R T
S
S L
S R
SSPU1

FIG. 1

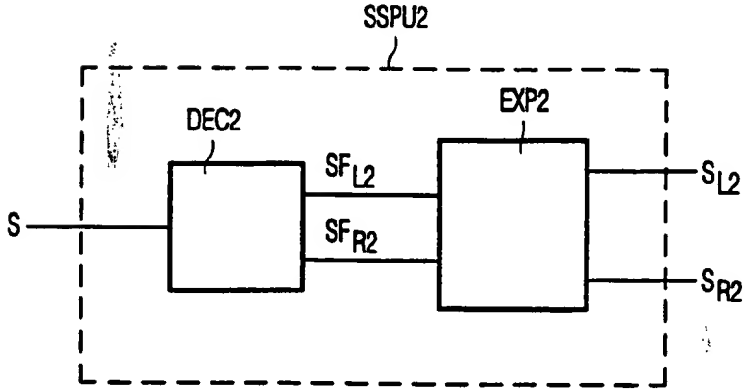
SSPU2
DEC2
EXP2
S
SF L2
SF R2
S L2
S R2

FIG. 2

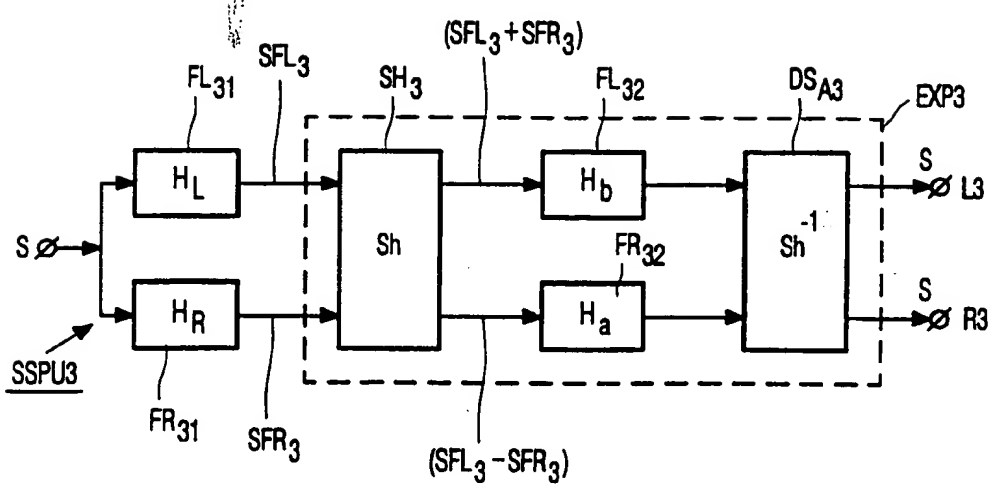

FIG. 3

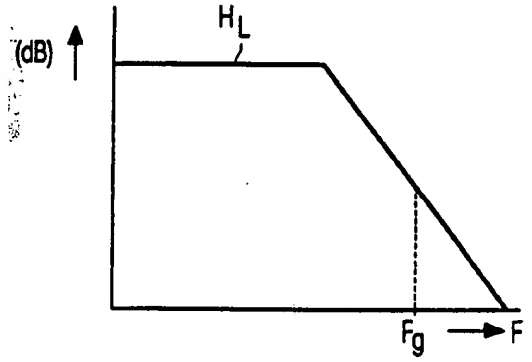

FIG. 4a

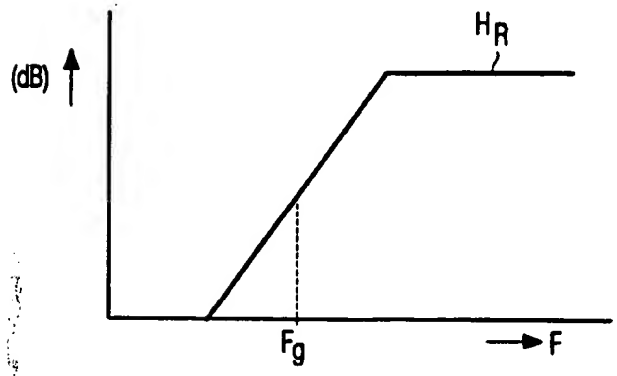

FIG. 4b

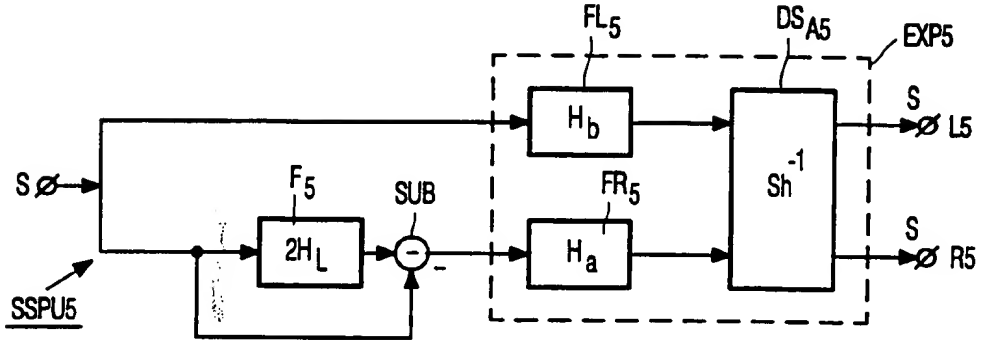

FIG. 5

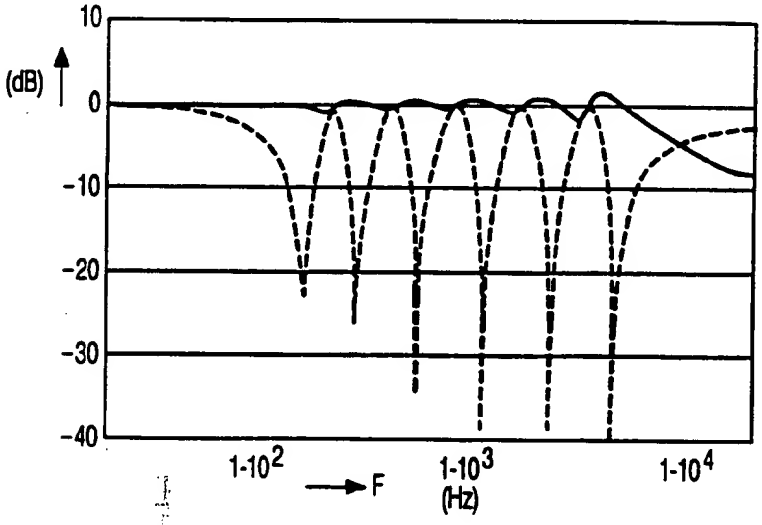

FIG. 6

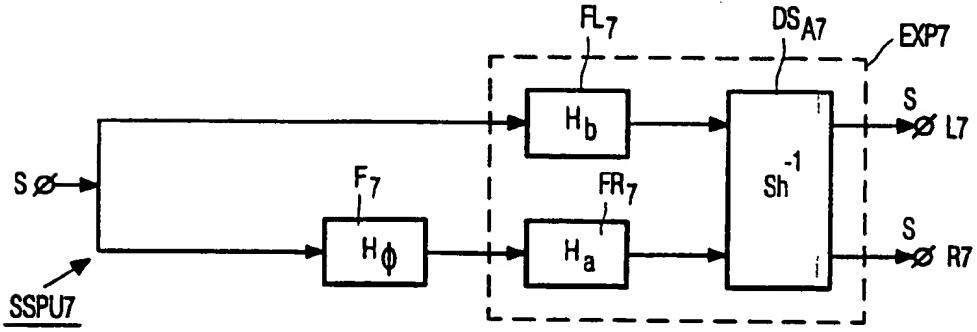

FIG. 7

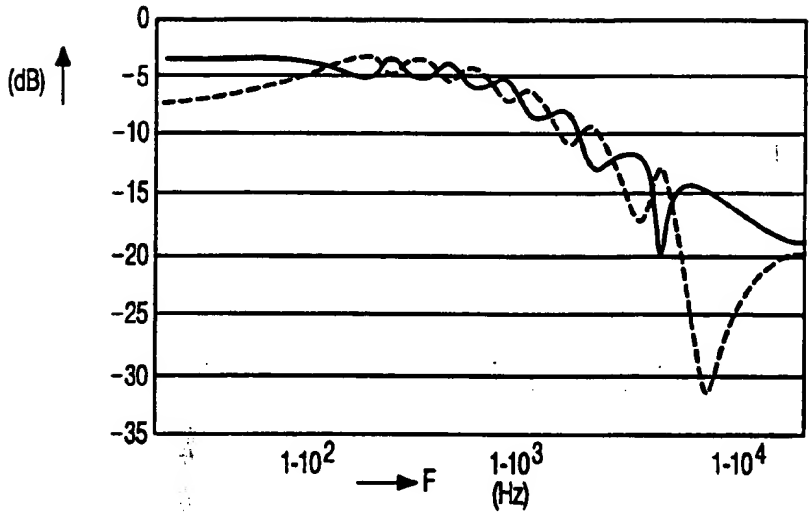
(dB)
0
-5
-10
-15
-20
-25
-30
-35
1-10^2
F
1-10^3
(Hz)
1-10^4

FIG. 8

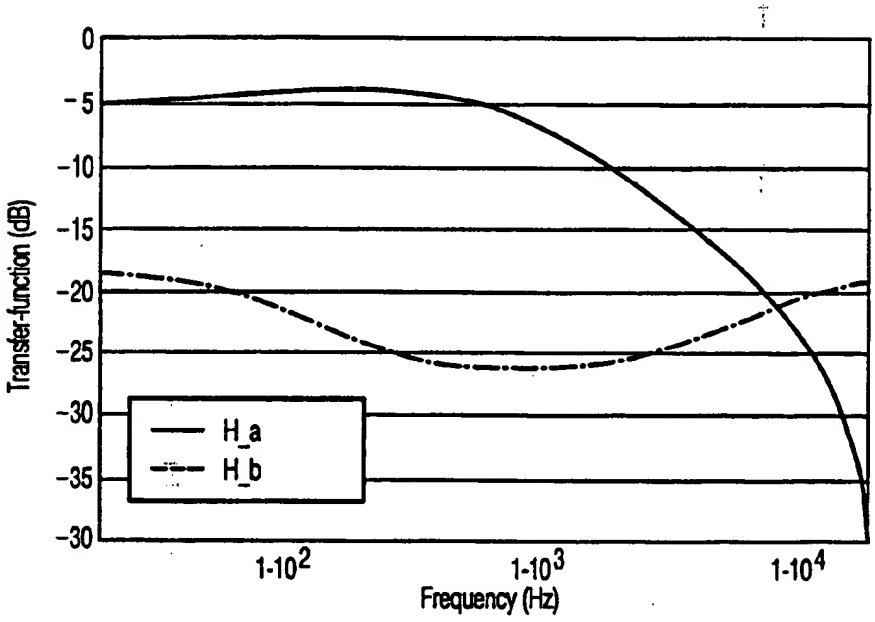
Transfer-function (dB)
0
-5
-10
-15
-20
-25
-30
-35
-30
H_a
H_b
1-10^2
1-10^3
1-10^4
Frequency (Hz)

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB/99/00165

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04S 3/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0724378 A2 (VICTOR COMPANY OF JAPAN, LIMITED), 31 July 1996 (31.07.96), column 4, line 16 - line 27; column 4, line 58 - column 5, line 2, figures 2,7	1,2
A	US 4121059 A (NAKABAYASHI), 17 December 1978 (17.12.78), filters 9,10, fig. 6 and filters 107, 107, fig. 8	1
A	US 4219696 A (KOGURE ET AL), 26 August 1980 (26.08.80), column 6, line 45 - line 51	1

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
15 June 1999	19 -06- 1999
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Leif Vingård Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

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PCT/IB 99/00165

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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